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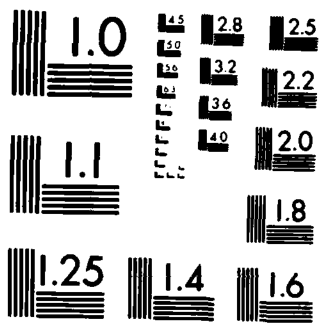

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POTHOLES, WEATHER, AND OTHER ENVIRONMENTAL CONDITIONS

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POTHOLES, WEATHER, AND OTHER ENVIRONMENTAL CONDITIONS

by

Michael A. Bilello

1. Introduction

As the objective of this workshop is to produce a state-of-the-art report on the causes and prevention of potholes, the intent of this part of the investigation is to summarize the various meteorological factors that contribute to the problem and to present data that should be considered in developing its solution. The specific subjects that will be discussed are freezing air temperatures, freezing indices, freeze-thaw cycles, and precipitation.

Other critical factors that should be considered in a discussion of potholes and weather are frost-susceptible soils, frost action, frost penetration, frost heaving, etc. Since descriptions of these various terms and processes are given in numerous reports, e.g. Department of the Army (1965), Sanger (1965), and Johnson et al. (1975), they will not be included here. These references contain detailed information and recommended procedures that are applicable to many issues pertinent to this workshop.

2. Definition of the Temperature Terms

Since air temperatures play an important role in the cause of pothole formation, it would be advisable to define the commonly used terminology and introduce the various associated abbreviations. The following definitions were obtained from Department of the Army (1965).

a) Average daily temperature (ADT): the average of the maximum and minimum temperatures for one day, or the average of several temperature readings taken at equal time intervals, generally hourly, during one day.

b) Mean daily temperature (MDT): the average of the average daily temperatures for a given day for several years.

c) Degree-days (DD): the number of degree-days for any one day, equaling the difference between the average daily air temperature and 32°F. The degree-days are negative when the average daily temperature is below 32°F (freezing degree-days) and positive when above (thawing degree-days). Figure 1 shows curves obtained by plotting cumulative degree-days against time.

d) Freezing index (FI): the number of degree-days between the highest and lowest points on a curve of cumulative degree-days vs time for one freezing season. It is used as a measure of the combined duration

and magnitude of below-freezing temperatures occurring during any given freezing season. The index determined for air temperatures at 4.5 ft above the ground is commonly designated as the air freezing index (AFI), while that determined for temperatures immediately below a surface is known as the surface freezing index (SFI).

e) Design freezing index (DFI): the average air freezing index of the three coldest winters in the latest 30 years of record. If 30 years of record are not available, the air freezing index for the coldest winter in the latest 10-year period may be used. To avoid the necessity for adopting a new and only slightly different freezing index each year, the DFI at a site with continuing construction need not be changed oftener than once in 5 years unless the more recent temperature records indicate a significant change in thickness design requirements for frost. The DFI is illustrated in Figure 1.

f) Mean freezing index (MFI): the freezing index determined on the basis of mean temperatures. The period of record over which temperatures are averaged is usually a minimum of 10 years, and preferably 30, and should be the latest available. The MFI is illustrated in Figure 1.

3. The Freezing Indices

AFI values should, insofar as possible, be based on actual air temperatures obtained from a station located as close as possible to the construction site. This is desirable because differences in elevations, topographical position, or nearness to cities, bodies of water, or other sources of heat may cause considerable variation in air freezing indices over short distances. These variations are of greater relative importance to design in areas of DFI of less than 1000 (i.e. MFI of less than about 500) than they are farther north.

Daily and mean monthly air temperature records for all stations which report to the U.S. National Weather Service (NWS) are available at the various NWS Centers. In general, at least one of these centers is located in each state. The MFI may be based on mean monthly air temperatures, but the DFI should be based on average daily air temperatures. Computation of values for determination of the DFI may be limited to consideration of only the coldest years in the desired cycle. These years may be selected by inspection of the tabulation of average monthly temperatures for the nearest first-order NWS station. A "Local Climatological Data" summary, containing this tabulation for the period of record, is published annually by the NWS for each of the approximately 150 U.S. first-order stations. If the temperature record of the station closest to the construction site is not long enough to permit the determination of mean or design index values, the available data should be related, for the same period, to those of the nearest station or stations of adequate record. Site index working values can then be computed based on this established relation and the indexes for the more distant station or stations.

The distribution of freezing conditions in the continental United States, based on NWS data, is illustrated by Figures 2 and 3, which show isolines of mean air freezing index for a normal year (Fig. 2) and the design freezing index (Fig. 3).

The DFI should be used in determining the combined thickness of pavement and base course required to limit subgrade frost penetration. As with any natural climatic phenomenon, colder-than-average winters occur with a frequency which decreases as the degree of departure from average becomes greater. Since an MFI cannot be computed in areas where temperatures do not fall below freezing every year, the DFI has been adopted so that the coldest years in a 30-year period can be used to determine the required protection.

4. Other Freezing Temperature Factors

As previously noted, freezing indices should be computed using actual air temperatures obtained from climatically representative weather sites. The variability in winter air temperatures that can be expected on a regional and local basis is shown in Figures 4 and 5 respectively. The curves in Figure 4 show the distribution of the mean number of days per year that minimum temperatures of 32°F or less are observed across the U.S. (U.S. Dept. of Commerce, 1975). Note the erratic pattern displayed by the isolines in the mountainous areas as compared to the even distribution over the central plains and observe that, on the average, even stations in southern Florida record minimum temperatures of 32°F or less at least once a year.

A map showing a detailed distribution of extreme minimum temperatures observed in and around Boston is shown in Figure 5 (Bilello 1968). The analysis shows the strong maritime-continental influence on winter temperatures, in that the extreme minimum values range from -14°F along the coastal regions to -36°F at locations about 40 miles inland from the coast.

In addition to local physical features, such as exposure and urban-suburban differences, certain micrometeorological factors may also be important. For example, differences may exist between air temperature observations taken from instruments in shelters at about 5 ft above the ground and those made at the ground surface. By day, temperatures decrease with height in the lower atmosphere and also with depth in the soil, a condition called a lapse profile in the atmosphere. By night the opposite situation occurs and is termed an inversion profile. The temperature gradient is greatest near the ground and the surface experiences the greatest diurnal range of temperature (Fig. 6, Oke, 1978). The actual difference between these values would vary from place to place and season to season. If significant differences (due to these and other meteorological factors such as solar radiation) are suspected at specific construction sites, it may be advisable to make surface temperature measurements at the time of the year when the differences would be critical.

Of course, another problem that must be considered is the 1 in 100- or 1 in 50 year air temperature anomaly. A good case in point is the severe winter of 1976-1977 when the temperatures from December through February averaged between 2° and 8°F below normal in the eastern half of the U.S. (Fig. 7, Wagner, 1977). However, the costs involved to prevent damage to roads and highways using temperature data based on very extreme conditions is always a point of debate.

5. Water Supply and Precipitation

A potentially troublesome water supply for frost heave is present if the highest groundwater table at any time of the year is within 5 ft of the proposed subgrade surface or of the top of any frost-susceptible base materials used. A water table at this depth or higher may be considered indicative of relatively adverse ground moisture conditions. When the depth to the uppermost water table is in excess of 10 ft throughout the year, ice segregation and frost heave may be expected to be reduced. Although this reduction in frost heave may be tolerable for flexible pavements, it may not be so for rigid pavements because of the cracking that may result in the latter, even under reduced heave. In homogeneous clay soils, the water content which the clay subgrade will attain under a pavement is usually sufficient to provide water for some ice segregation even with a remote water table. Closed-system laboratory tests on silt, clays, and tills, corresponding to a field condition of a very deep water table, indicate that detrimental ice segregation is unlikely if the moisture content of these soils is below 70 percent of the saturation value. However, full advantage can rarely be taken of this because moisture contents near complete saturation may occur in the top of a frost-susceptible subgrade from surface infiltration through pavement and shoulder areas or from other sources (Department of the Army, 1965).

The height of the water table at specific locations just prior to the start of freezing air temperatures is dependent on several factors, including soil type, drainage and proximity to water sources. The amount of precipitation occurring in the area of interest before freezeup is also crucial to the level to which water is stored in the soils. Climatic information on the rain and snowfall characteristics for specific areas would be useful for the design and construction of roads of frost-susceptible soils. Figure 8 shows the mean annual distribution of the number of days with precipitation of 0.01 in. or more across the U.S. (Landsberg, 1974). Better detail of the total mean annual precipitation can be obtained from studies of more local areas as shown in Figure 9 for Boston and nearby regions. However, it would be even more useful to use monthly precipitation values (Fig. 10) because storage of water in the soils is monthly or seasonally dependent.

The amount of surface and groundwater available during winter thaws and spring breakup is also crucial to the pothole problem. The local distribution of snowfall amounts (potential meltwater), as shown in Figure 11, and the monthly total precipitation amounts during the spring months (Fig. 10) are the type of climatic data that would be helpful in preparing for such adverse environmental conditions.

6. Freeze-thaw Cycles and Potholes

The following text was summarized from TM 5-818-2 (Department of the Army, 1965).

When ice segregation has occurred, reduction of the strength of the soil with a corresponding reduction in load-supporting capacity of the pavement develops during frost-melting periods, particularly early in the spring when thawing is occurring at the top of the subgrade and the rate of melting is rapid. As illustrated in Figure 12 melting of the ice from the surface downward releases water that cannot drain through the still-frozen soil below or redistribute itself readily. Excess moisture from the wet and softened subgrade soil moves upward into the base course, then laterally to the nearest drain. If drainage provisions are inadequate, the base course may become completely saturated. If this occurs, the bearing capacity of the base course is substantially reduced, the effects of possible subsequent frost action are increased, water and fines may be pumped through joints and cracks, and accelerated deterioration of the surfacing may occur. The possible effects of restriction of subsurface drainage by frozen soils should be considered at all points in drainage design.

Supporting capacity may be reduced in clay subgrades even though significant heave has not occurred, because water for ice segregation is extracted from the voids of the unfrozen clay below, and the resulting shrinkage of the latter largely balances the volume of the ice lenses formed. Also, traffic may cause remolding or the development of hydrostatic pressures within the pores of the soil during the period of weakening, thus resulting in further reduced subgrade strength.

The degree to which a soil loses strength during a frost-melting period and the length of the period during which the strength of the soils is reduced depend on the type of soil, temperature conditions during freezing-and-thawing periods, the amount and type of traffic during the frost-melting periods, moisture supply during fall, winter, and spring, and drainage conditions.

Since freeze-thaw cycles contribute to the formation of potholes, data on their frequency of occurrence would be of interest. Hershfield (1974) used data from 1300 climatic summaries to construct a map for the conterminous U.S. showing the annual frequency of freeze-thaw cycles (Fig. 13). The maximum freeze-thaw activity, about 250 days per year, occurs in the mountainous regions of the west where the isopleths exhibit a complex frequency pattern. The average number of days with freeze-thaw cycles per year in the New England states ranges from 80 to 120 days.

Hershfield notes that "a freeze-thaw cycle is said to have occurred if the temperature crossed the freezing point during a calendar day. This is sometimes referred to as a frost-change day. The number of days on which the temperature crossed the freezing point is the frequency variable of interest." The author also points out that "since the study

is based on observations taken at an elevation of about 5 feet, the results are conservative compared to those that would result from observations taken at a lower elevation." This statement is based on measurements conducted at Coshocton, Ohio, as reported by Hershfield (1979), in which greater frequencies of freeze-thaw cycles were observed at 2 in. above the ground than at 5 ft above the ground (Fig. 14).

7. Pothole Occurrences and Concurrent Weather

Since there are numerous direct and indirect factors that can cause the formation of potholes, attempts to associate the phenomenon directly to one or two weather conditions becomes difficult. For example, in addition to the effects of freezing temperatures, freeze-thaw cycles and precipitation, pothole frequency could be due to poor drainage systems, insufficient base course depth (or material), traffic intensity and loads, maintenance procedures, and the original condition of the road. Unfortunately, information of many of these contributing factors is either unavailable or not recorded. It is also especially difficult to combine or integrate the parameters to determine the total effect with respect to pothole formation. Another problem to consider in evaluating the statistics of pothole occurrence is whether attempts to separate small (minor damage) from larger potholes (requiring considerable repair) are equally accounted for in the number of reported cases.

Although many of the previous multiple conditions confuse the total picture to some extent, history has shown that particularly severe winters produce excessive numbers of potholes. For example, Hershfield (1979) notes that: "the winter of 1977-78 may truly be called the 'winter of the pothole' because so many of them pockmarked the roads in the northeast quadrant of the United States." His analysis of the frequency of freeze-thaw cycles for that year, however, revealed that the winter of 1977-78 for this region actually had the smallest number of cycles as compared to the previous 18-year record (Fig. 15). Hershfield suggests that freeze-thaw cycles are not necessarily the essential ingredient for the formation of potholes. Rather, it is the sequence of very wet soil conditions followed by persistent cold temperatures that leads to uneven downward movement of the freezing isotherm and will cause heaving and road deterioration. The winter of 1976-77 in the eastern half of the United States was colder than in 1977-78, but Hershfield points out that the winter of 1977-78 was accompanied by record-breaking snows over much of the Northeast.

Although the northern half of the United States observed fewer freeze-thaw cycles (due to the persistent cold) throughout the winter of 1977-78, the penetration of the freezing air temperatures during this winter resulted in more frequent freeze-thaw cycles in many states south of the Mason-Dixon line (Fig. 15). It would be of interest to evaluate the changes in the number of observed potholes in these border states during the winters of 1976-77 and 1977-78, when freezing temperatures and frequent freeze-thaw cycles occurred in these southern regions.

The only other record of pothole frequency available for this study was obtained from "The Road Information Program" (TRIP 1980). The record contained a "pothole per mile" estimate for states participating in a survey of the 1979-80 winter road damage. An attempt was made to associate the recorded number of potholes per mile for most of the reporting states with observed air temperature departures from normal for the spring months (U.S. Dept. of Commerce 1980) (Fig. 16). The variability of reported potholes from state to state with temperature departures for March through May (or even for December 1979 through February 1980 which showed a similar departure pattern), did not provide conclusive results. This indicates that combinations of several of the previously stated factors, plus a reliable pothole reporting system, is required in order to obtain useful relationships between the environment and pothole formation.

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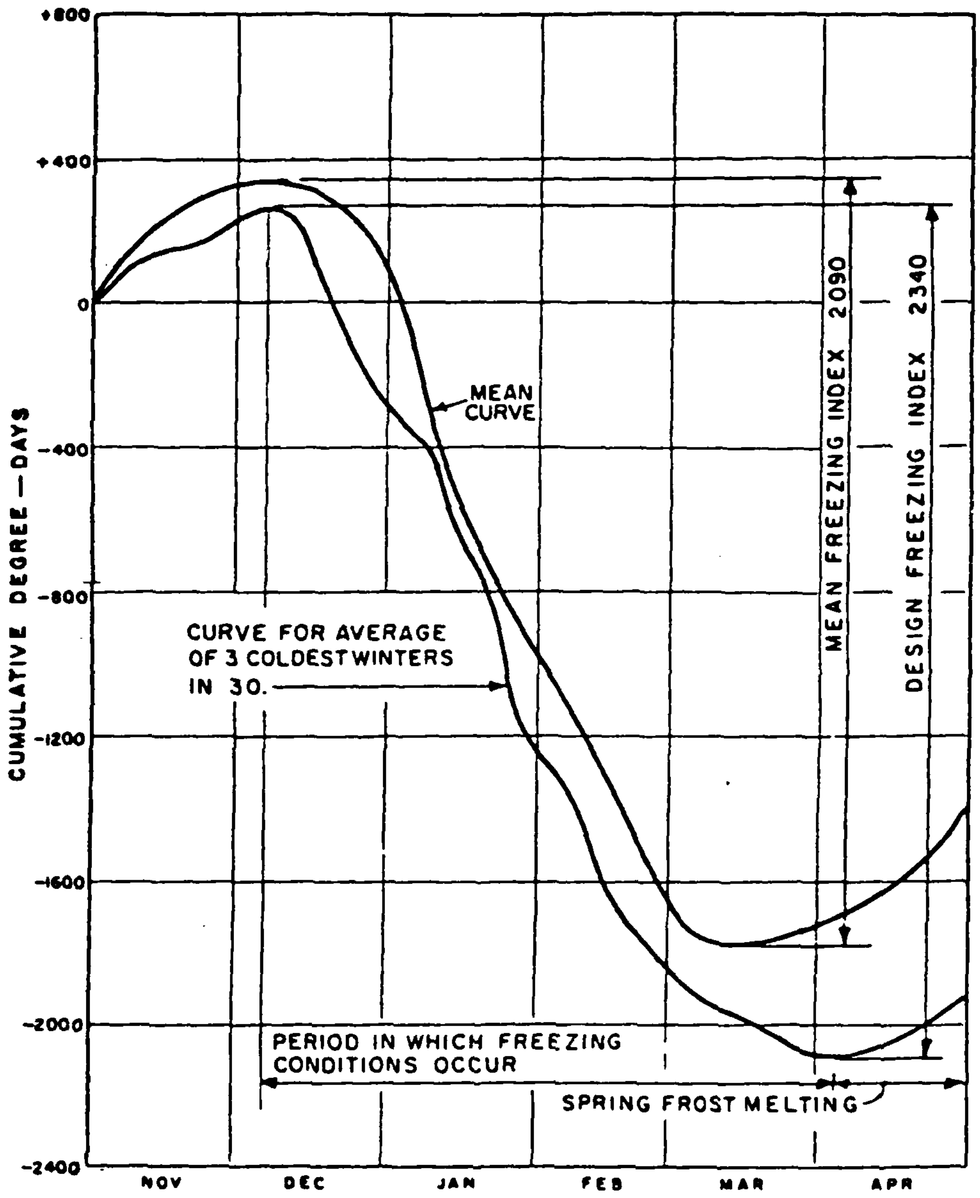


Figure 1. Determination of freezing index (Department of the Army, 1965).

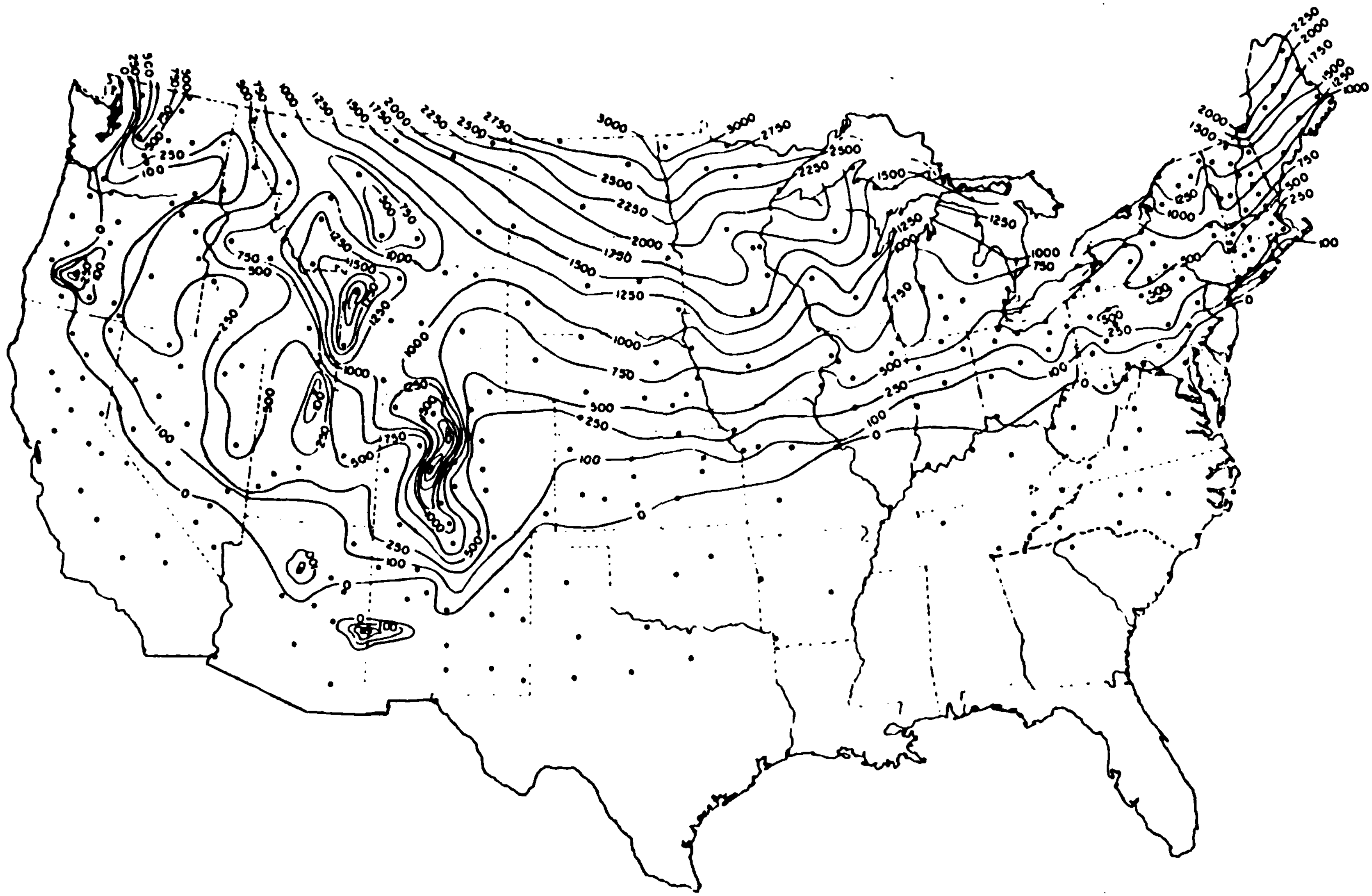


Figure 2. Distribution of mean air freezing index values in the continental U.S. (Department of the Army, 1965).

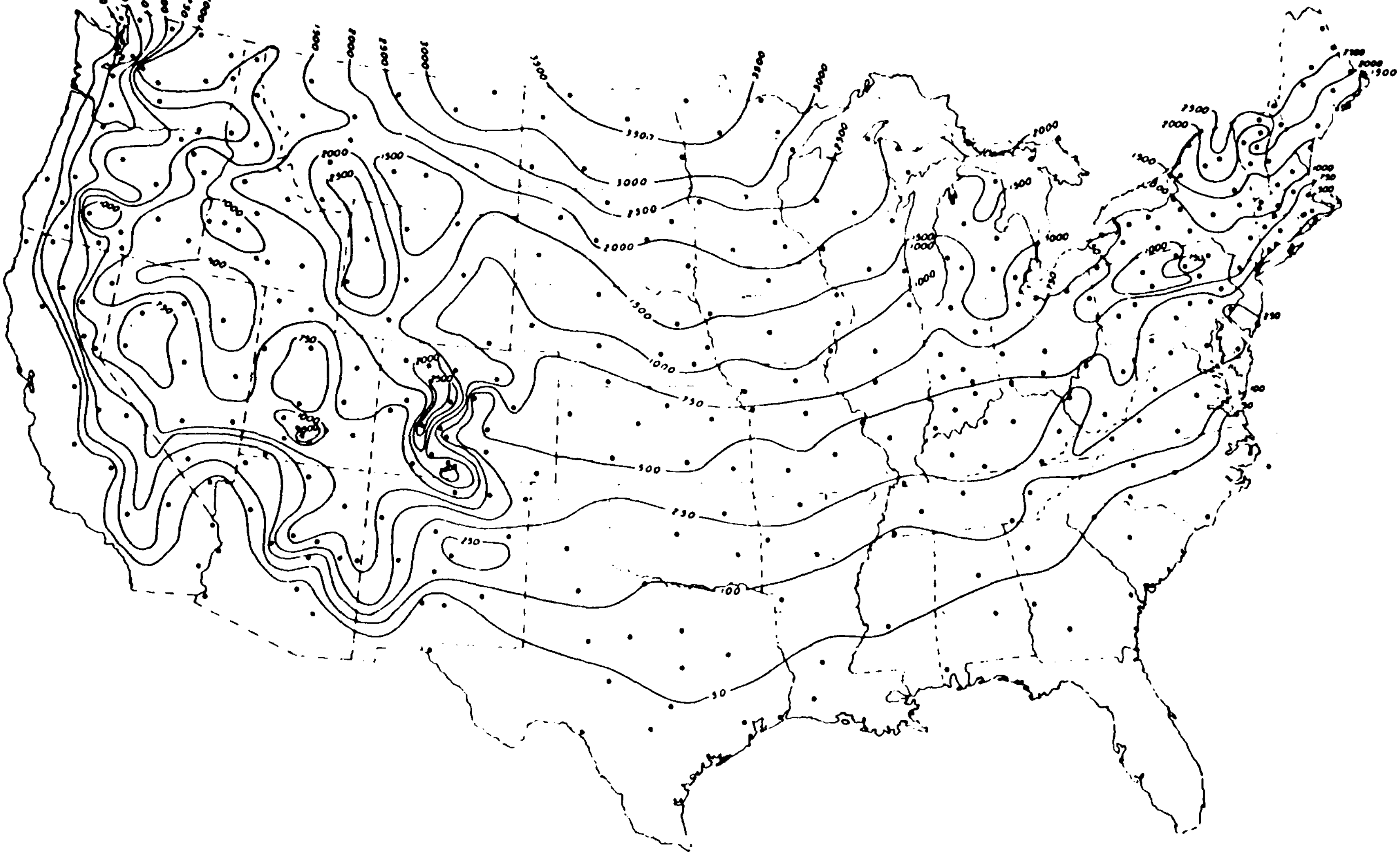


Figure 3. Distribution of design air freezing index values in the continental U.S. (Department of the Army, 1965).

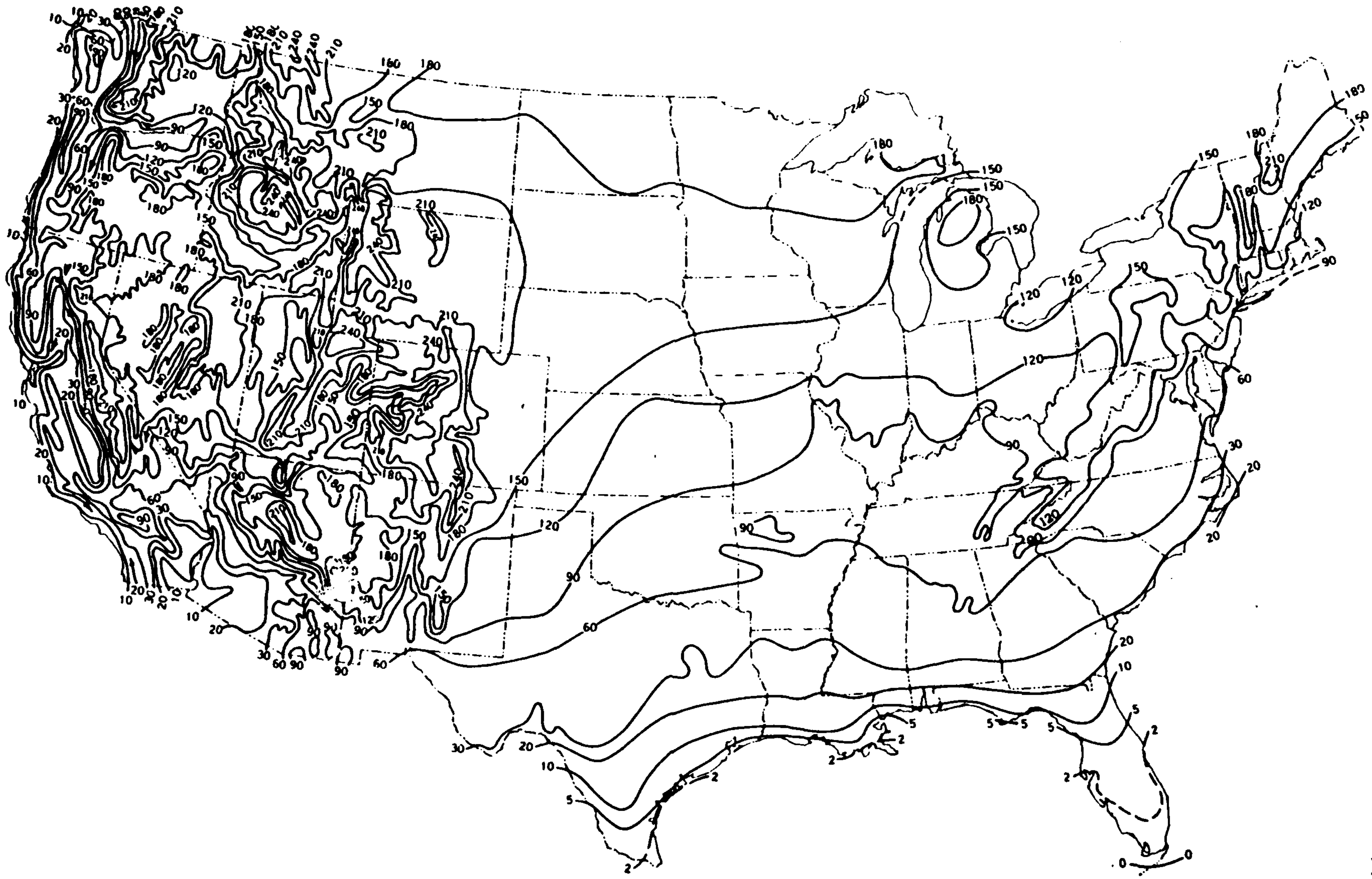


Figure 4. Mean number of days with minimum air temperatures of $32^{o}F$ and below (U.S. Department of Commerce, 1975).

0 50 100 200 300 400 500 MILES

BASED ON PERIOD OF RECORD THROUGH 1964

NOTE.--Caution should be used in interpolating on this generalized map. Sharp changes in the mean number of days 32°F and below may occur in short distances, due to differences in altitude, slope of land, type of soil, vegetative cover, bodies of water, air drainage, urban heat effects, etc.

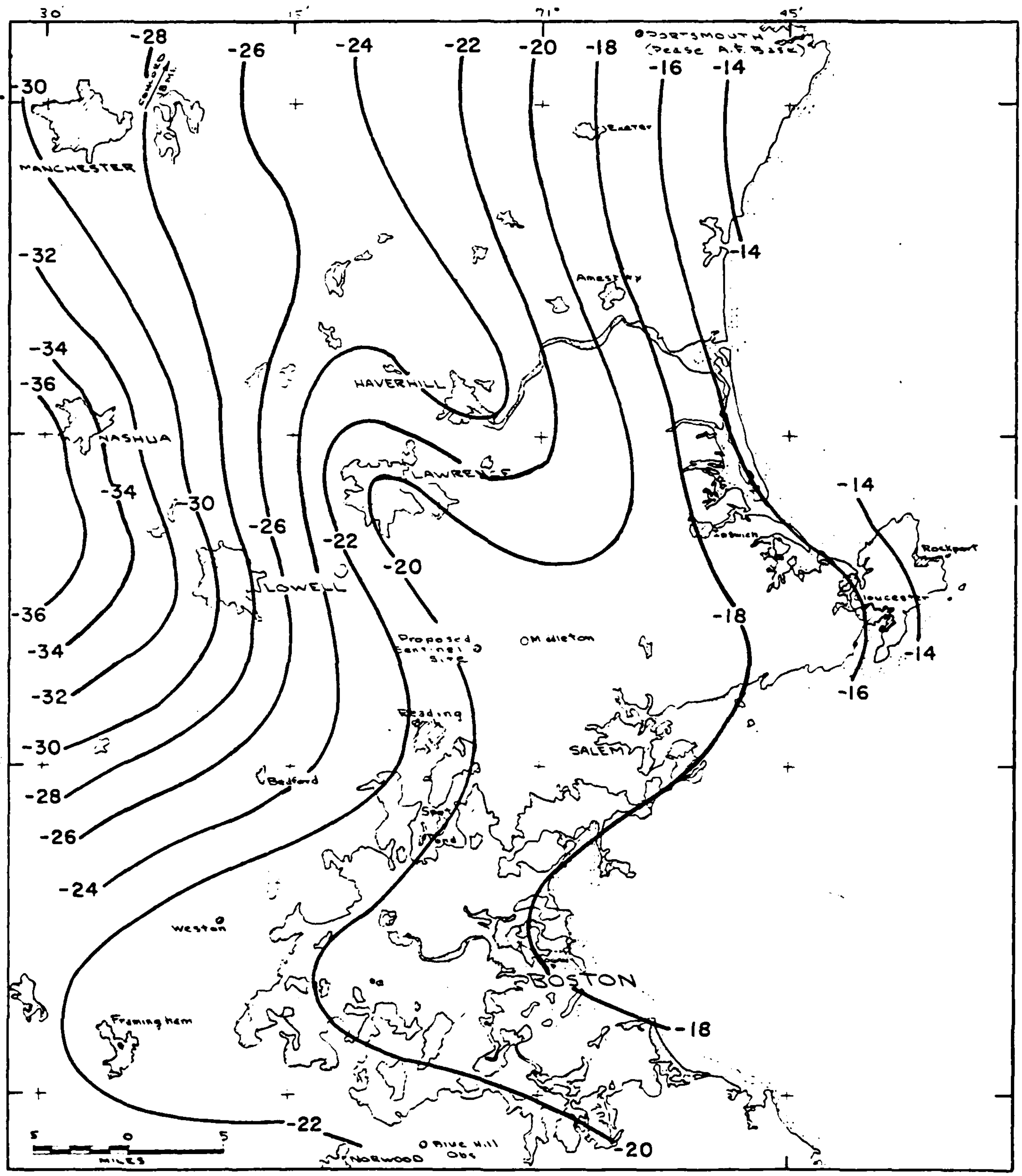


Figure 5. Extreme observed minimum air temperatures (^{o}F) for southeastern New Hampshire and northeastern Massachusetts (Bilello, 1968).

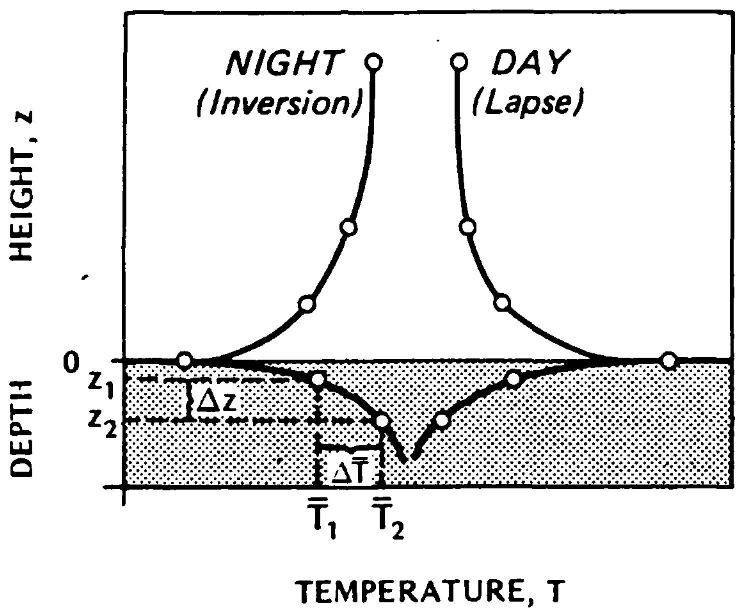


Figure 6. Idealized mean profiles of air and soil/atmosphere interface in fine weather (Oke, 1978).

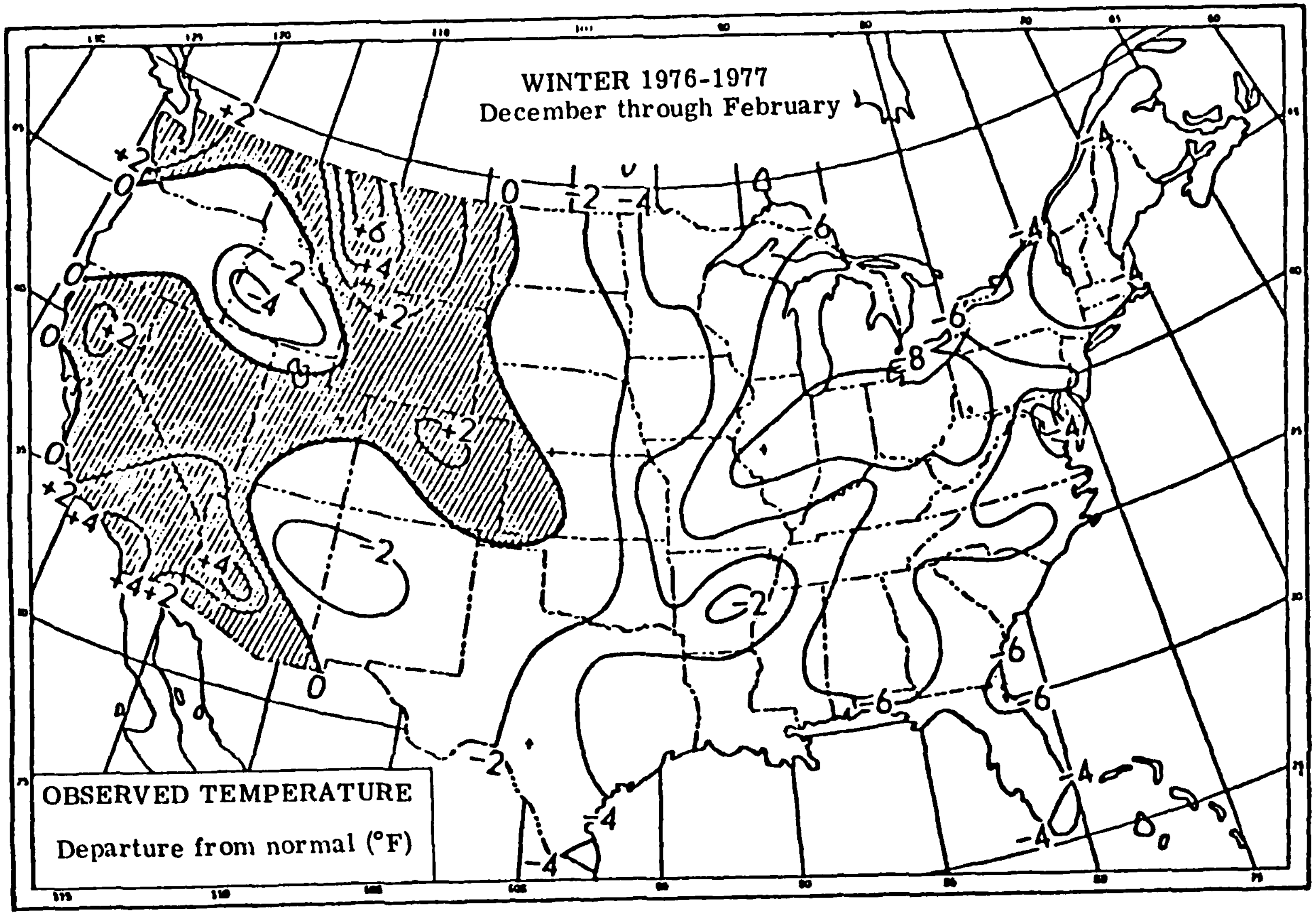


Figure 7. Temperature anomaly pattern for the 1976-77 winter over the U.S. computed from data of approximately 100 stations (Wagner, 1977).

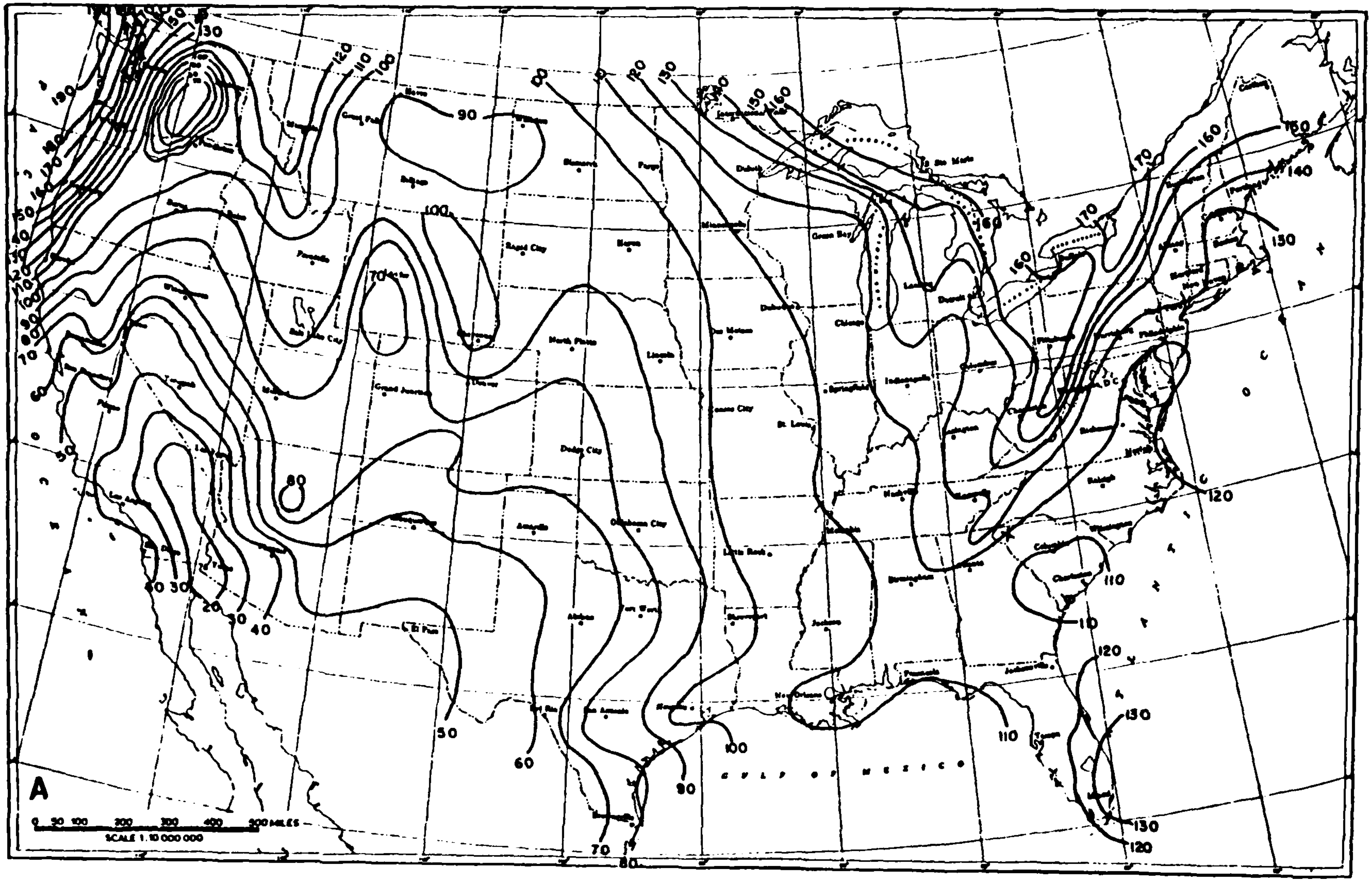


Figure 8. Mean annual number of days with precipitation of 0.01 inch or more (Landsberg, 1974).

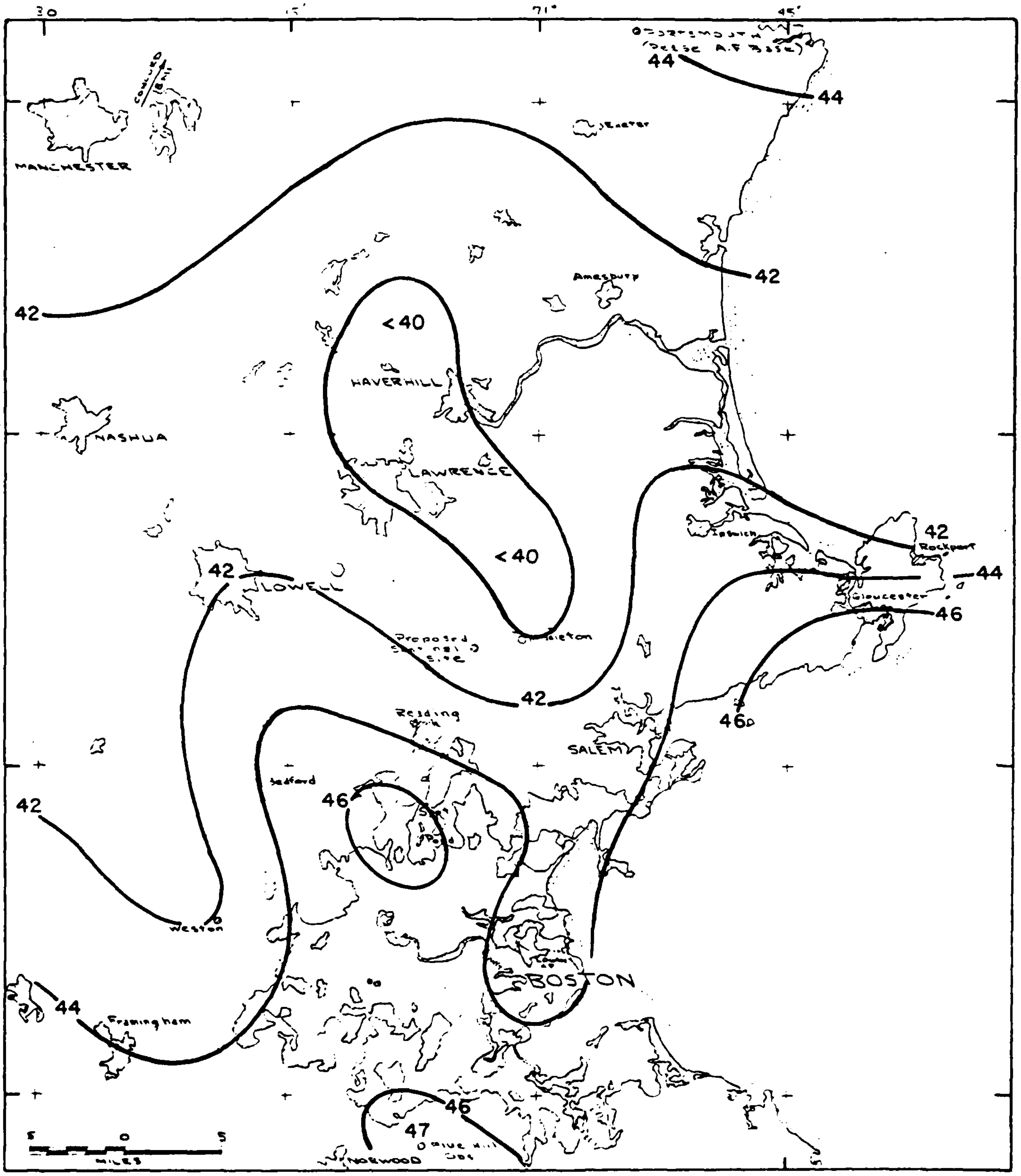
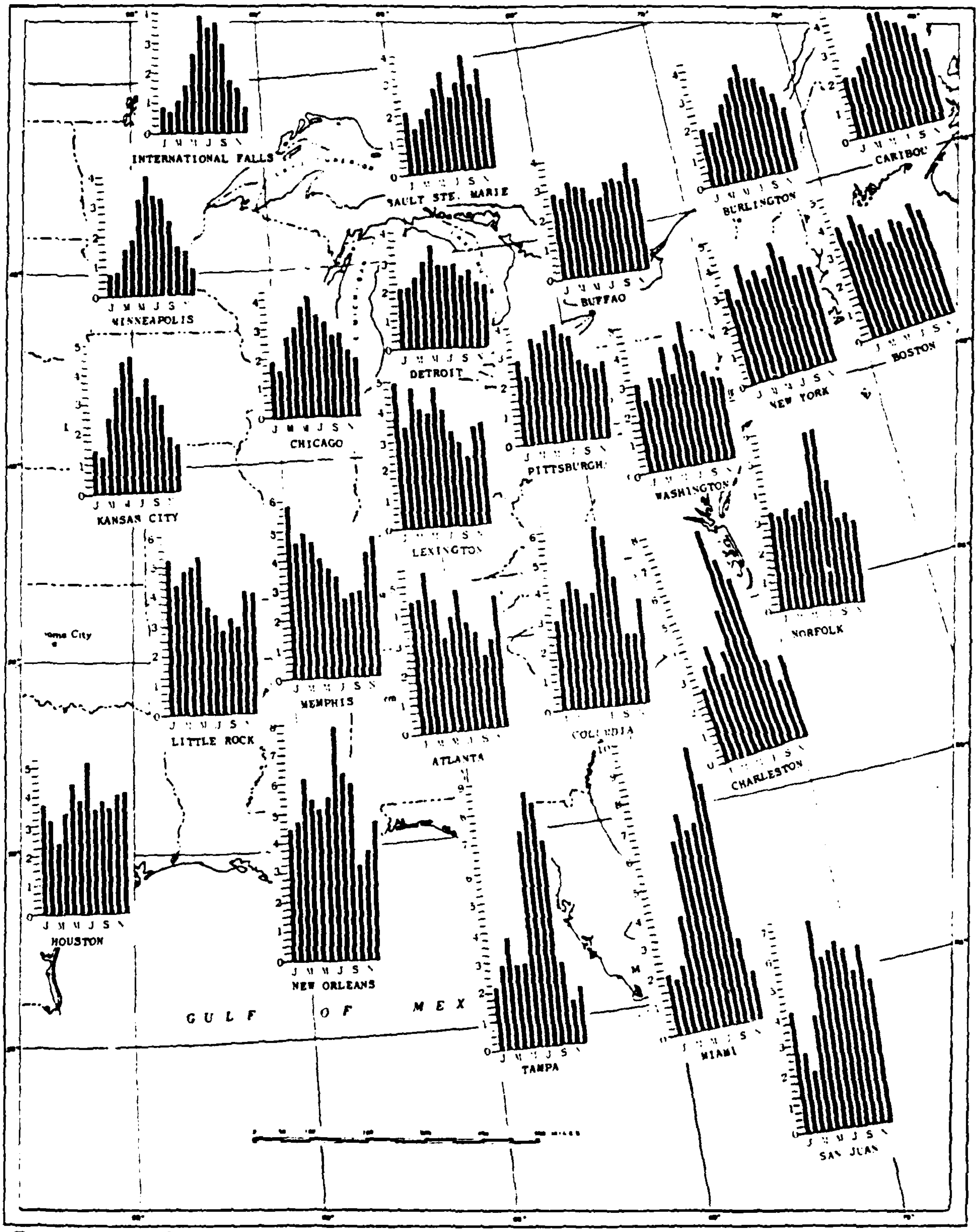


Figure 9. Total mean annual precipitation (inches) for southeastern New Hampshire and northeastern Massachusetts (Bilello, 1968).



Based on 30-year Period, 1931-60

Figure 10. Normal monthly total precipitation (inches) for 1st order weather stations in eastern U.S. (U.S. Department of Commerce, 1975).

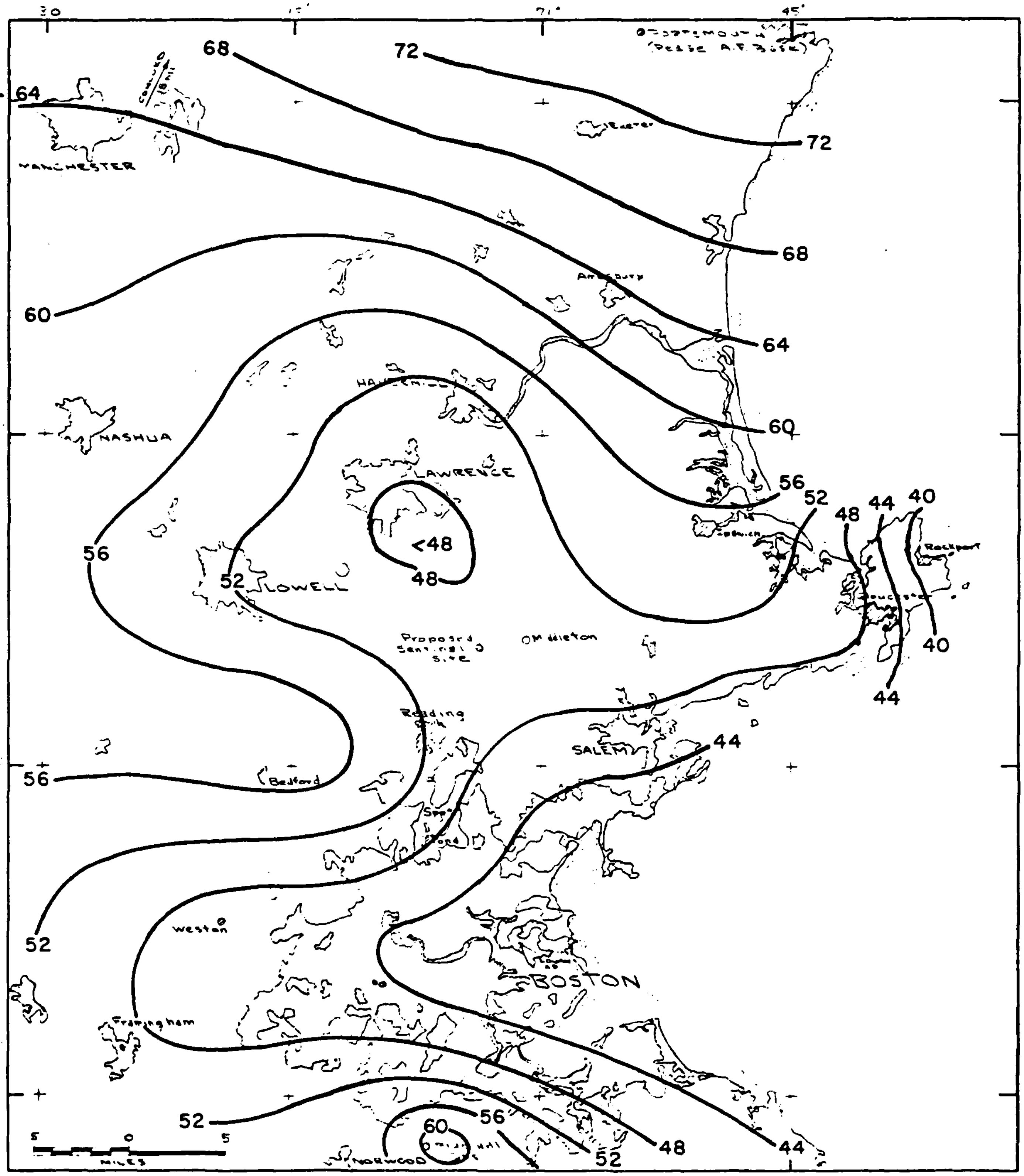


Figure 11. Total mean annual snowfall (inches) for southeastern New Hampshire and northeastern Massachusetts (Bilello, 1968).

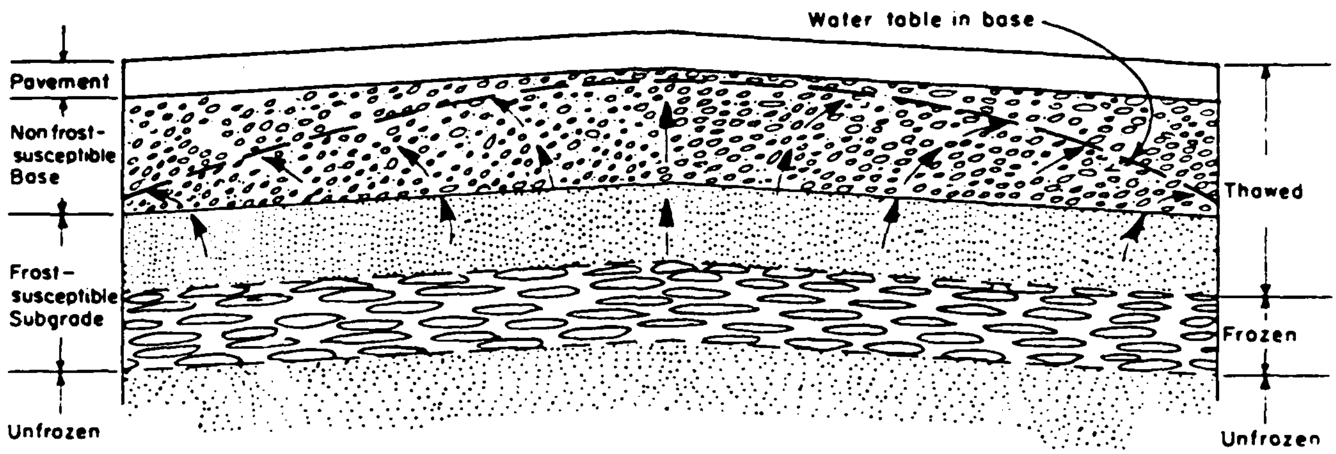


Figure 12. Moisture movement upward into base course during thaw (Department of the Army, 1965).

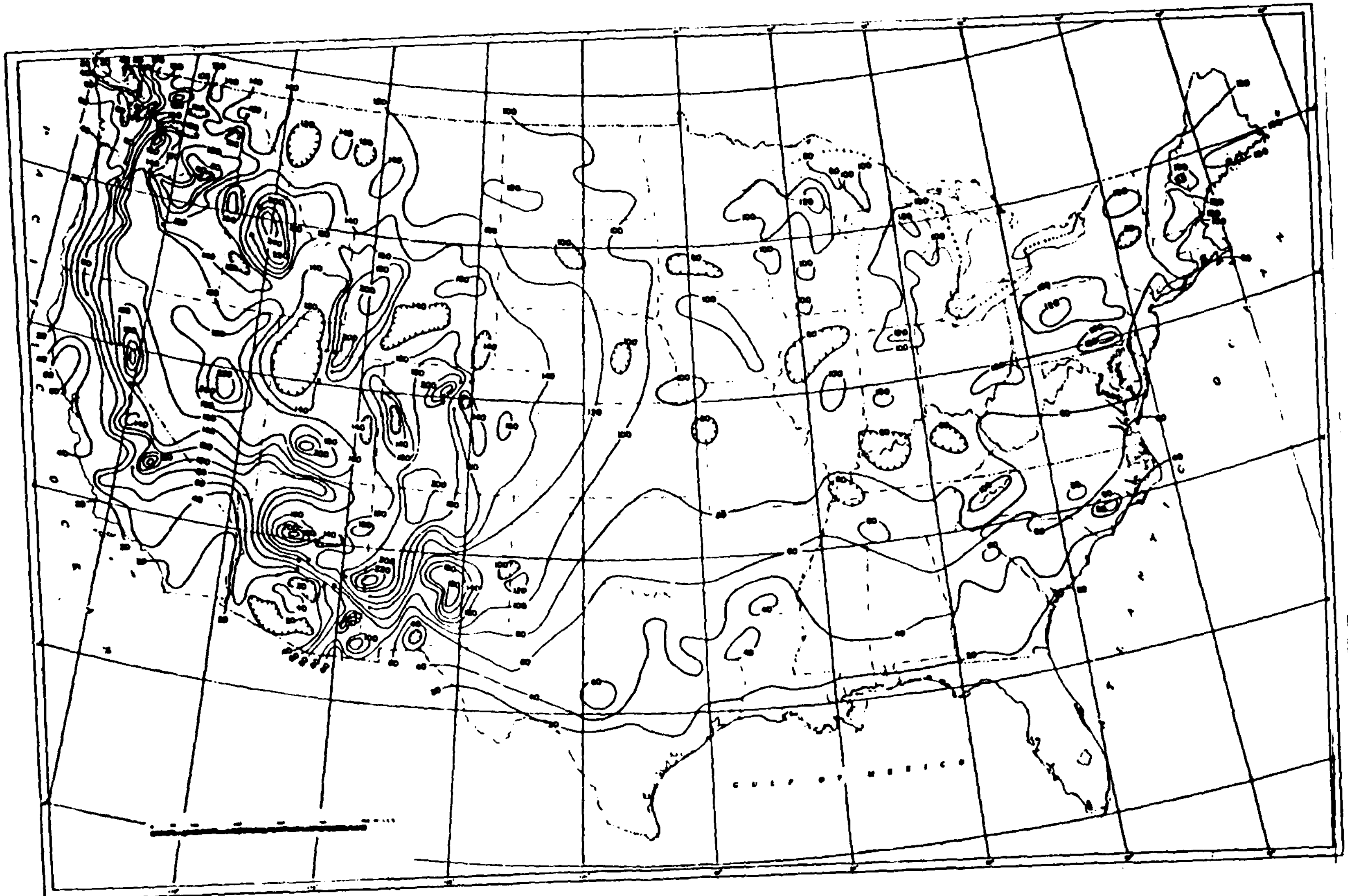


Figure 13. Mean annual frequency (days) of freeze-thaw cycles (Hershfield, 1974).

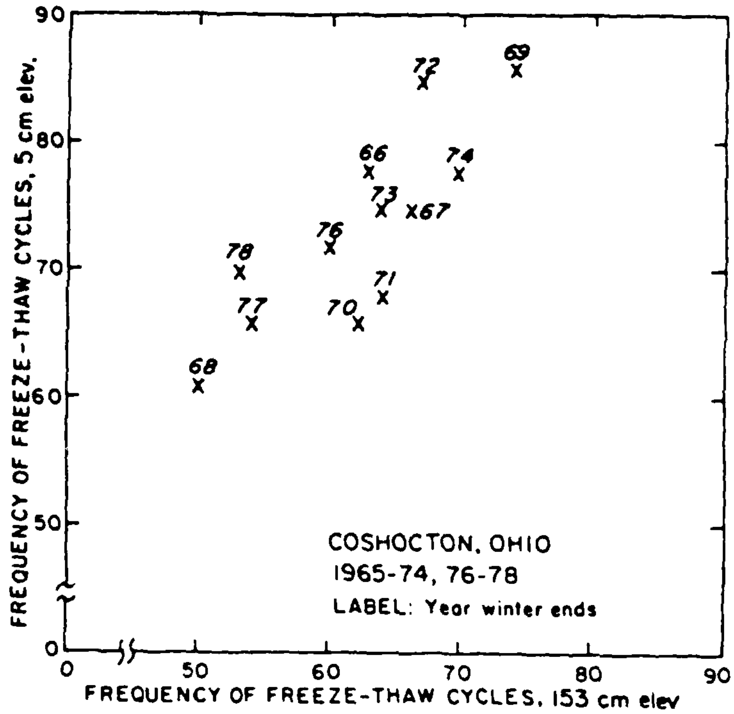


Figure 14. Relationship between the annual winter (Nov-Mar) frequency of freeze-thaw cycles at two elevations (Hershfield, 1979).

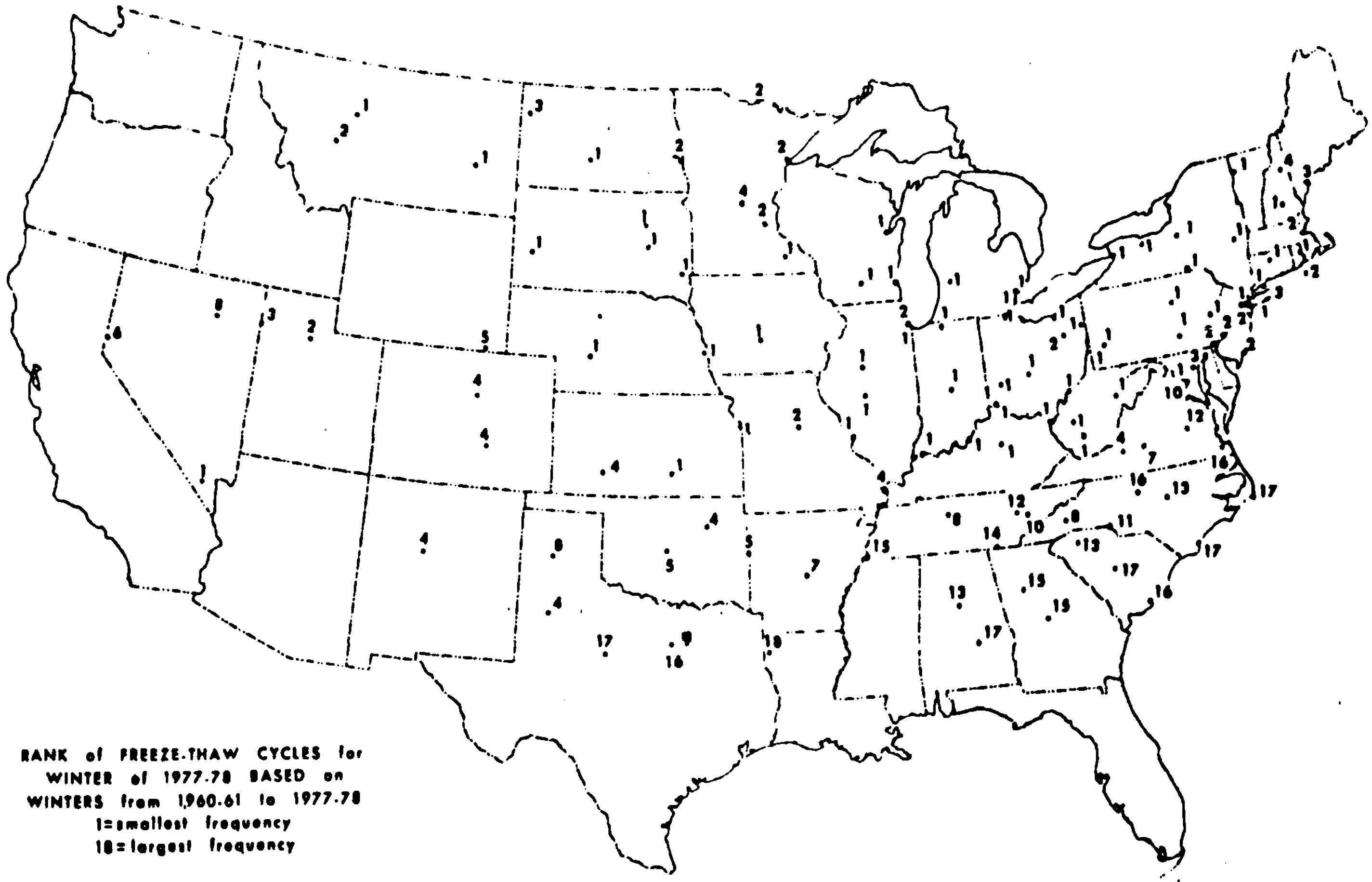


Figure 15. Rank of the magnitude of freeze-thaw cycle frequency for the winter of 1977-78 (Hershfield, 1979).

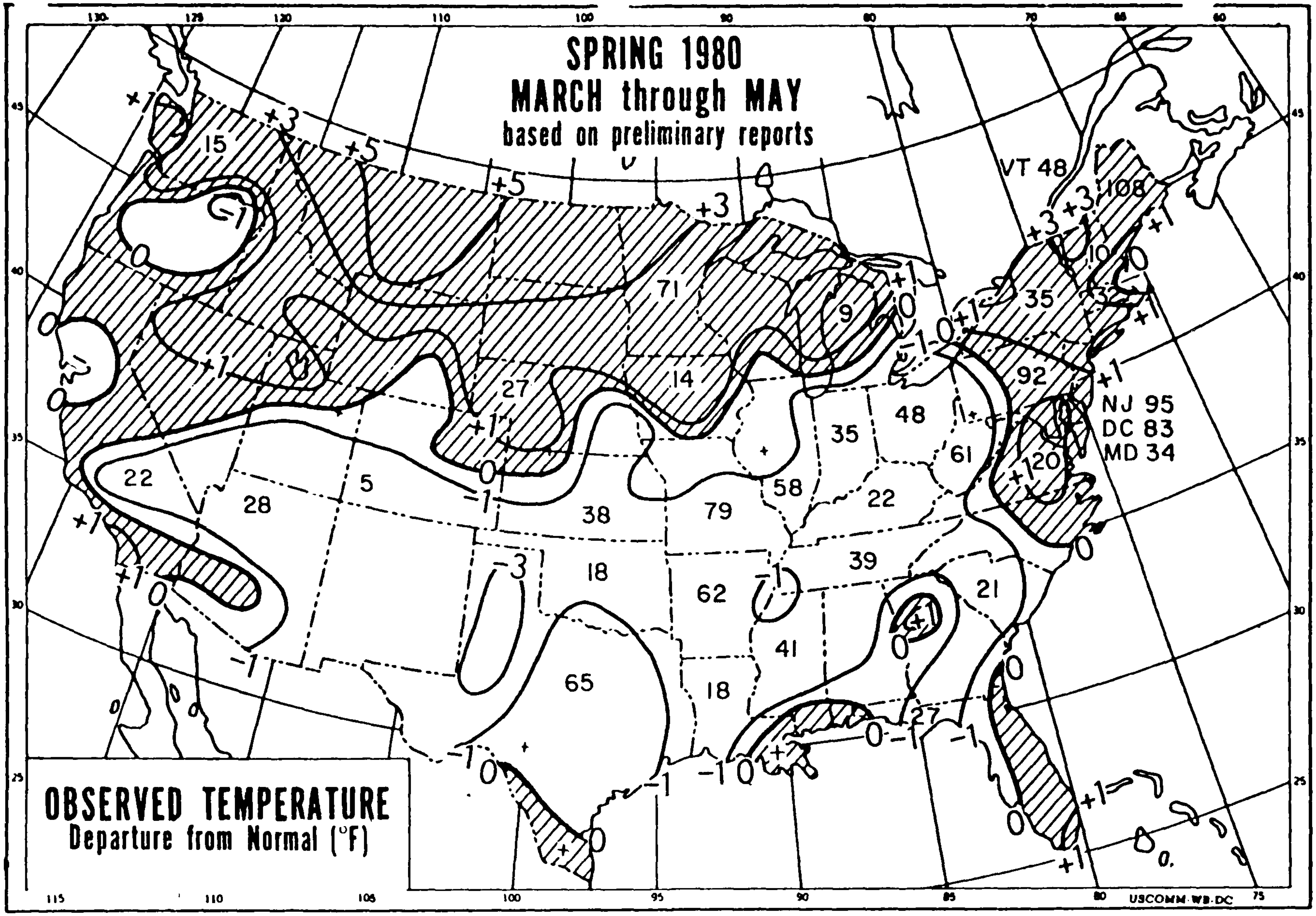


Figure 16. Distribution of the number of reported potholes per mile (smaller numerals shown by states) for the winter of 1979-80, and associated with observed air temperature departure from normal for the Spring months (U.S. Department of Commerce, 1980; and TRIP, The Road Information Program, 1980).

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